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The application of pulse altimeter for linear references detection

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Abstract

Algorithm of linear references detection is based on statistical processing of reflected pulse altimeter signal. It is assumed that linear references formed from two underlying surfaces and differences between statistical distribution of pulse amplitude depend on the type of underlying surface. The differences allow us to decide which type of surface reflects our signal. To do this we use the method of maximum posteriori probability. This paper describes how to determine the position of linear reference and what the accuracy of this process is. The minimum of maximum posteriori probability is closely connected with linear reference position. We use this fact to detect the linear reference position. This algorithm allows us to realise autonomous navigation. We use Doppler sharpening to increase the accuracy of detection of linear reference position and increase the number of discriminated surfaces.

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1. Introduction

Paper [1] stressed the necessity of creating a stable navigation system for airborne vehicles, which is independent from Sputnik Navigation System (SNS). In the study we used an onboard pulse radar altimeter as a sensor with carrier wave length 7cm, which allows us to increase the robustness and accuracy of the navigation system. This algorithm is created for tracking part of trajectory, when evolutions are less than 10˚.

When trying to solve this problem we found that properties of terrains are different and some of them should be classified. The main source of terrains combination is [2] and we used some other unofficial sources to fill the terrain

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base. We used this information during our study and it was found that the backscattering diagram (BSD) is closely connected with statistical distribution of the amplitude of reflected signal.

The application of modern methods of beam sharpening allows to increase the spatial resolution and the number of etalons. Also we found that using of metamaterials allows to realise frequency-selective system for precise backscattering diagram analyse and decreasing antennas dimensions twice and more [4, 5].

As result we calculated the probability of correct discrimination. According to the statistical theory, when we compare two or more processes we compare two or more distributions in accordance with a priori hypotheses, at first we got these distributions from [2], in this source all types of surfaces have a maximum probability of about 0.9 (because they are situated between 5% and 95%, other 10% are spread very widely to use this information). The normalized crossed square is the probability of false detection (if we compare two different types of distributions) or true detection (if we compare two similar distributions).

Information analysis in [1] gives us table 1 of typical terrains combinations with qualitative characteristics. It was shown that the width of the backscattering diagram (Θ_{DOR}) and the reflection coefficient (K) are the most important parameters that influence the ability of terrains discrimination. This information allows us to group terrains by the ability of discrimination into table 1.

Table 1. Terrains comparison.

Qualitative Characteristic	Easy to discriminate	Discrimi-nated	Hard to discrimi-nate	Impossible to discriminate
Angles, ˚	0–10 and more	0–3	0–3	–
ΔK, dB	>10	about 10	1–7	More than half of std
Combination of terrains	FW, GW, MW, BW	AF, AB, AM, CF	AS, GC, BC, SC	FB, FN, GN and etc.

In this table we used the following abbreviations: A – asphalt, B – bushes, C – concrete, F – forest, G – grass, M – meadow, N – ground, S – snow, W – water.

The use of table 1 allows us to choose some interesting cases for further exploration: well discriminated surfaces are combinations of terrains: the first terrain with large width of backscattering diagram (Θ_{DOR}=4°), such as “water” (in some cases little width of backscattering diagram, such as “asphalt” (Θ_{DOR}=1.5°)) and large backscattering coefficient (“water” has K=20dB) and the second surface with large width of backscattering diagram (Θ_{DOR}>10°) and low backscattering coefficient (K<5dB).

Paper [1] described a mathematical model for exploring the algorithm of border detection that should be used for exploring linear references (LR).

This model is based on phenomenological model, which is described in [3], and it is referred to as the facet model, where each facet is an elementary reflector with the following parameters: normal of facet orientation, effective backscattering coefficient and bias for average level. During the first stage the values of the main parameters (vehicle position, parameters of signal and underlying surface, Doppler filter and etc.) are set. The next step is creating the surface with LR. Then we in cycle compute signal from each facet and accumulated signal with proper delays for current position, and make vehicle move over the generated surface. The reflected signal for each facet is evaluated from the radar equation [3]. For our algorithm we need an envelope, which is introduced as accumulated signal.

As it was shown in [1], the amplitude of the reflected signal from most typical terrains has Rayleigh distribution, which has only one parameter. This fact allows us to discriminate terrains by integral statistic of reflected signal by comparing accumulated distribution with etalon distribution.

At first, we explored the dependence of possible level dispersion on the type of underlying surface. For the range of possible level we used edge values of probability of correct discrimination of 0.5. This dependence looks like Rayleigh distribution but raised on fixed level on ordinates axis.

We explored the dependence of correct probability on the height of flight. And we found that the amplitude is proportional to height.

For example, we have normalized level of 0,4 for “forest-asphalt” combination, it means that for combination of “asphalt” and “forest” underlying surfaces we have value 0,4 (it should be volts) accurate to constant (which we measure in real experiment). Now we can discriminate surfaces, based on these numbers (if more –“asphalt”, less – “forest”).

Then we explored the dependence of correct probability discrimination on the parameters of Doppler filter: they are angle from nadir direction (α) and width of Doppler filter (*d*). And we found that optimal $\alpha = 0^\circ$ and *d* is minimal, but it depends on the necessary accuracy and the number of accumulated pulses.

2. Main Part

Figure 1 shows the comparison process – the base of detection algorithm and algorithm of signal processing.

First we collected the amplitude of the reflected signal for etalon histogram (where we know the terrain type), then we did the same for unknown terrain type (amplitudes got during the flight).

Then we made the necessary transformations for comparison process (they are shown in fig. 1). And finally we computed the crossed square; it is the probability of correct detection (discrimination of terrains).

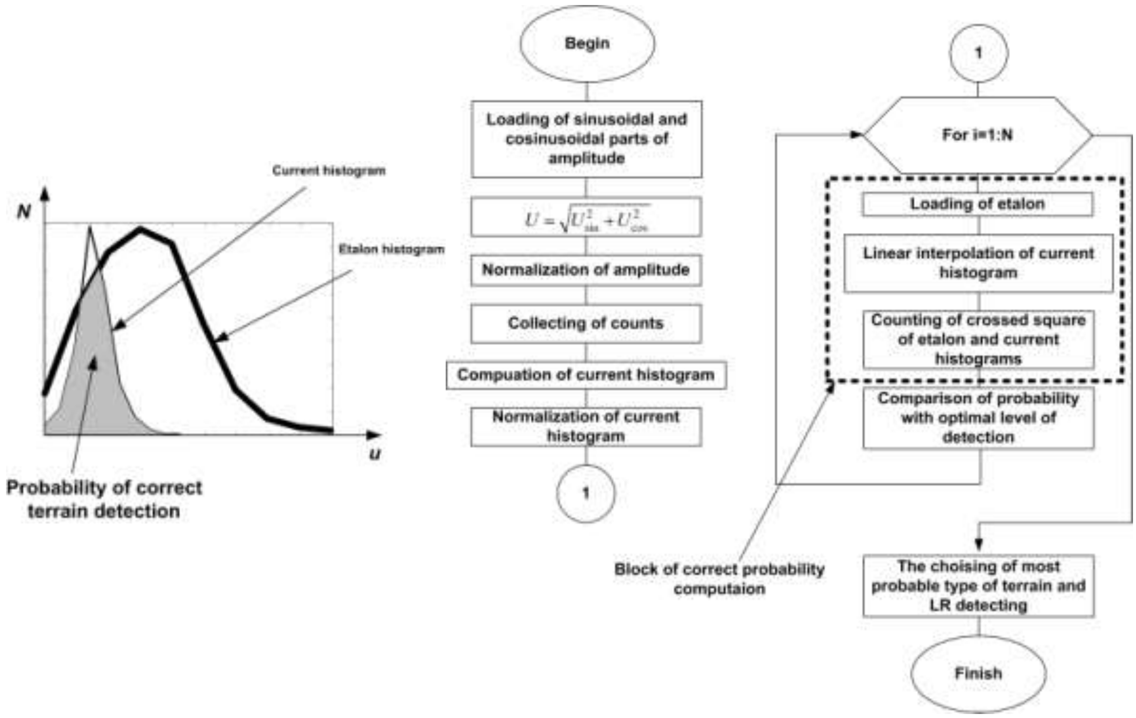

Fig. 1. Comparison process and algorithm

We carried out the experiment of LR detection in the following sequence. First we modelled the situation to collect the necessary statistics for each position. Figure 2 shows the way to collect dataset.

In this figure we can see that the airborne vehicle trajectory starts above the “surface1”, where there is only one surface in exposure spot, throw linear reference formed by “surface2” to “surface1” at finish position. For each position we collected the dataset to create the probability distribution for each position.

Then we compared the etalon distribution with the current distribution, as a result we obtained the current probability of correct discrimination assuming that we have “asphalt”, for example. And we have another hypothesis that we have “forest”.

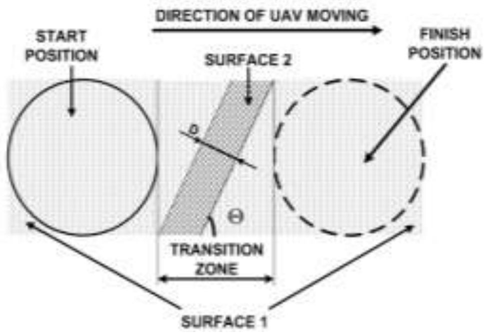

Fig. 2. Model experiment for LR detection.

Then on the whole trajectory we built a curve for each hypothesis for two possible situations and found the maximum of posteriori probability. The result is shown in fig. 3.

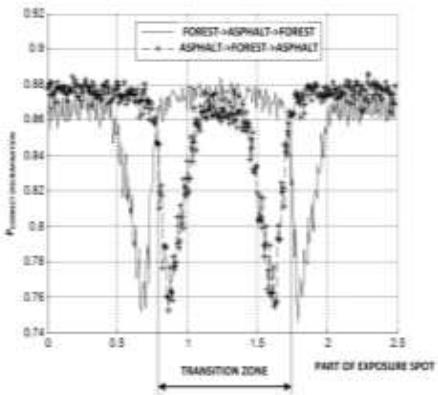

Fig. 3. Detection of LR position with D=0.8 parts of exposure spot.

The minimum of function in fig. 3 (maximum of posterior probability) corresponded to the linear reference position. Some of terrain combinations cannot be detected, and table 2 shows those terrain combinations, which can be detected by this algorithm in case φ=40–90°.

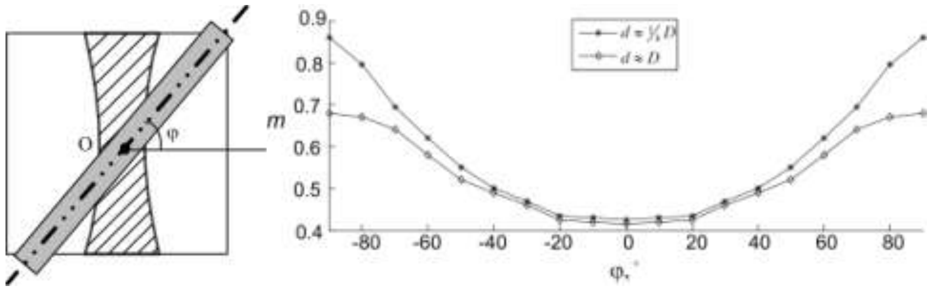

Fig. 4. Model experiment for LR orientation.

For better understanding of Doppler filtration (DF), applied to LR, we carried out an experiment that shows part of LR square in Doppler stripe (m). As it is shown in Fig. 4, if we have φ=90°, m – is the biggest, but, if φ decreased to 30°, we have m<0,5. And this fact gives us a limit of φ=40°, which should give a gain in using DF.

Table 2. Ability of LR detection.

D=0.1	D=0.2	D=0.4	D=0.8
FAF, FWF, GWG, NGN, BWB, MWM, SWS	FAF, FWF, GWG, NGN, BWB, MWM, SWS	FAF, FWF, GWG, NGN, BWB, MWM, SWS, WGW, WBW, WMW, WSW, SNS	FAF, FWF, GWG, NGN, BWB, MWM, SWS, WGW, WBW, WMW, WSW, SNS, CFC, FCF, WFW, GNG

This table gives us information about combinations of surfaces, which should be detected during the flight. The best linear reference is “water” on some spreading terrains, like “forest” or “meadow”. It is important to mention that the real width of LR strongly depends on the height of flight, and thin LR should be detected on lower height.

We made two flights over flat terrain with different types of underlying surfaces (see fig.5). The routes were similar, but the weather conditions were different: in the first flight it was dry, and in the second flight it was wet and rainy.

During the flight we collected dataset in receiver, parameters of flight, GPS coordinates and video stream of terrain. After preliminary processing we obtained the dependence of reflected signal amplitude distribution on time. We processed two flights: the first flight, which we used as etalon, was in humid conditions and the other was in dry conditions, which we used for checking.

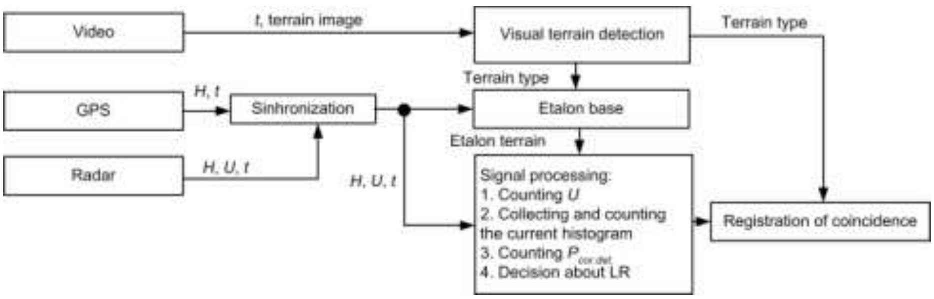

Fig. 5. The flight experiment.

After processing the first flight we obtained the information about four types of underlying surfaces: “water”, "forest", "ground" and "meadow". The flight over these types of terrains gives us sufficient information for creating histograms. These types of terrains are extended enough during the flight for collecting dataset.

During the flight we crossed a lot of LRs, combined from targeted terrains.

Then we processed the dataset with the introduced algorithm and as result found that "water" should be detected in "forest" with probability of correct detection more than 0.7 for D~0.8 and with probability of more than 0.5 for D~0.2. Other terrains like "forest", "meadow" and "ground" also should be detected with $P_{cor.\ det.}>0.5$ at D>0.4. We were not able to analyze "asphalt" terrain, because we have no good etalon, but further experiments should give us the necessary information. The use of DF allows us to detect narrow LRs. For example, we have extracted all narrow rivers (with 0.1<D<0.2) and some narrow stripes of "meadow" and "ground". But for "forest" the best results were for typical use of pulse altimeter.

3. Conclusion

In this study we obtained the following important results.

We described the base of linear references detection algorithm. Then we applied the results from [1] for detection of linear references. Two main parameters influence discrimination ability: the width of BSD and the backscattering coefficient. We also briefly described the mathematical model as an instrument for exploration.

We carried out some necessary experiments to understand which types of linear references should be detected, and we found that "water" is very good as LR and it should be detected with D>0.1 and φ=40–90°.

After that we tested this algorithm in two flight experiments (see fig. 5) over flat terrain with different types of underlying surfaces. The routes were similar, but weather conditions were different.

As a result we applied the algorithm of surfaces discrimination to linear references and found that it is works correctly in flight experiments. Therefore we should evolve this algorithm to increase the number of detected LR and its probability of correct detections.

In furtherer explorations we will concentrated on precise analyse of BSD by the application of metamaterials applied to radar altimeters antenna.

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